

**FACILITATING CONSTRUCTIVIST *E*-LEARNING  
BY SOFTWARE AGENTS**

**A thesis submitted for the degree of  
Doctor of Philosophy**

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# CERTIFICATE

Date: **January 2007**

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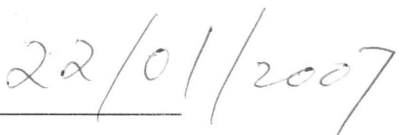
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is the result of my original research, except where otherwise acknowledged within the text. It has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I also certify that the thesis in whole or in part has not previously been submitted for any other degree.

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*To my wife Ping Gu and our lovely daughter Chaoyu Pan*

## ABSTRACT

*E*-learning is being taken as an important means to satisfy the increasing demands for learning in today's information society. Although considerable research effort has been devoted to facilitating *e*-learning, very little has been done to support constructivist *e*-learning. This research attempts to develop an online constructivist learning environment (CLE) and utilize software agents to provide supportive services for learners to facilitate and assist them to build knowledge by using constructivist ways.

Constructivists assume knowledge is *constructed* by learners. Learners are knowledge-constructors whereas teachers are facilitators for the construction. Constructivist learning theory provides a framework to develop an online CLE. The important issues are concerned with what supportive services should be provided for learners and how to provide these services.

The services identified in the work include:

- providing access to appropriate learning resources and learning strategies;
- fostering meaningful interactions with content, teachers, and fellow learners;
- supporting personalized learning for individual learners;
- facilitating collaborative learning among learners in groups; and
- aiding to timely evaluate learning outcomes.

An innovative strategy is adopted to organize these services. They are provided for learners in *non-intrusive* ways. Learners are *not* forced to accept any of the services. They can *autonomously* take control over their learning. Meanwhile, they are offered services through suggestion or advice. These spontaneous services help them solve various possible problems in learning and assist them to progress in the online learning process.

All the supportive services are adapted to individual learners. Three key adaptations, *service content*, *presentation manner*, and *intervention degree*, are applied. Profiles are built to characterize individual learning characteristics, including *knowledge constitution*, *cognition ability*, and *learning styles*.

All the services are dynamically generated based on actual learning scenes. A learning process specification language, built upon Koper's EML, is developed to describe the learning activities and processes and the corresponding supportive services.

A new type of agents, *process agents*, is developed to realize the services. Three classes of agents, *personal assistant agent*, *planning agent*, and *managing agent*, have been incorporated into the learning environment to provide support for learners. They work in the background, monitor and evaluate individual learner's learning, and provide supportive services for learners whenever necessary. Together they play a role of "*constructivist teacher*".

To demonstrate the work, a system prototype has been developed and a number of services have been implemented. A preliminary evaluation has illustrated the agent-based approach can facilitate construction of knowledge by individual learners.

## LIST OF ASSOCIATED PUBLICATIONS

The following is a list of my research papers published in referred international journals and referred international conferences during my PhD study at UTS, starting from July 2003.

### *Referred international journals*

1. Pan, W. & Hawryszkiewicz, I. (2006) **Assisting Learners to Dynamically Adjust Learning Processes by Software Agents**. *International Journal of Intelligent Information Technologies*, 2(2). pp. 1-15.
2. Pan, W., Huang, M. L. & Hawryszkiewicz, I. (2005) **A Software Agent Based Searching Approach for Constructivist Learning Over the Internet**. *INFOCOMP - Journal of Computer Science*, 4(2). pp. 1-8.

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1. Pan, W. & Hawryszkiewicz, I. (2006) **Facilitating Knowledge Construction by Providing Individualized Services**. To be published in the APSCE 14th International Conference on Computers in Education (ICCE 2006), Beijing, China, Nov 30-Dec 4, 2006. pp. 603-610. ISO Press. (ISBN: 1-58603-687-4)
2. Pan, W. & Hawryszkiewicz, I. (2006) **Using Software Agent Technology to Support E-Learning**. IASTED International Conference on Education and Technology (ICET 2006), Calgary, Alberta, Canada, Jul 17-19, 2006. pp. 67-72. ACTA Press. (ISBN: 0-88986-581-7)
3. Pan, W., Hawryszkiewicz, I. & Xue, D. (2006) **Facilitating Collaboration among Students in E-Learning by Software Agents**. The IADIS International Conference on e-Society, Dublin, Ireland, Jul 13-16, 2006. pp. 81-85. (ISBN: 972-8924-16-X)
4. Pan, W. & Huang, M. L. (2006) **A Visual Interface to Assist Learners to Inspect Learning Plans**. AACE World Conference on Educational Multimedia, Hypermedia & Telecommunications (ED-MEDIA 2006), Orlando, FL, USA, Jun 26-30, 2006. pp. 703-710. (ISBN: 1-880094-59-2)
5. Pan, W. & Hawryszkiewicz, I. (2005) **Facilitating Constructivist Learning through Managing Learning Processes**. The 8th IASTED International Conference on Computers and Advanced Technology in Education (CATE 2005), Oranjestad, Aruba, Aug 29-31, 2005. pp. 197-202. ACTA Press. (ISBN: 0-88986-522-1)
6. Pan, W. (2005) **An Agent-based Approach to Assisting Learners to Dynamically Adjust Learning Processes**. The 12th International Conference on Artificial Intelligence in Education (AIED 2005), Amsterdam, Netherlands, Jul 18-22, 2005. pp. 905-907. ISO Press. (ISBN: 1-58603-530-4)
7. Pan, W. (2005) **Assisting Learners to Dynamically Adjust Learning Processes by Software Agents**. The IADIS International Conference on e-Society, Quwra, Malta, Jun 27-30, 2005. pp. 601-605. (ISBN: 972-8939-03-5)

8. Pan, W. & Hawryszkiewicz, I. (2004) **A method of defining learning processes.** *Australian Society for Computers in Learning in Tertiary Education Conference (ASCILITE) 2004*. Perth, Australia, Dec 5-8, 2004. pp. 734-742. (ISBN: 0-9751702-3-6)
9. Pan, W. (2004) **An Agent-based Approach to Facilitate Personalized Learning over the Internet.** *International Conference on Computers in Education (ICCE 2004)*, Melbourne, Australia, Nov 30 - Dec 3, 2004. pp. 237-244. (ISBN: 1-86335-573-1)
10. Pan, W. & Hawryszkiewicz, I. (2004) **To Develop Constructivist Learning Environments on the Web Using Software Agent Technology.** The 7th IASTED *International Conference on Computers and Advanced Technology in Education (CATE 2004)*, Kauai, Hawaii, USA, Aug 16-18, 2004. pp. 236-241. (ISBN: 0-88986-422-5)
11. Pan, W., Huang, M. L. & Hawryszkiewicz, I. (2004) **Finding Appropriate Learning Resources over the Internet with the Assistance of Software Agents.** The 2004 *International Conference on Internet Computing (IC'04)*, Las Vegas, Nevada, USA, Jun 21-24, 2004. pp. 565-571. (ISBN: 1-932415-45-9)
12. Pan, W. & Hawryszkiewicz, I. (2004) **Software Agents for Facilitating Collaboration among Students in e-Learning.** *AACE World Conference on Educational Multimedia, Hypermedia & Telecommunications (ED-MEDIA 2004)*, Lugano, Switzerland, Jun 21-26, 2004. pp. 761-768. (ISBN: 1-880094-53-3)
13. Pan, W. & Hawryszkiewicz, I. (2004) **A Multi-Agent Architecture to Support Collaboration in e-Learning.** *International Conference on e-Education 2004: Review and New Perspectives*, Macao, Jun 24-25, 2004. pp. 343-352. (ISBN: 99937-33-65-2)
14. Pan, W. (2004) **Support Personalization of Learning on the Web by Software Agents.** *IASTED International Conference on Artificial Intelligence and Applications (AIA2004)*, Innsbruck, Austria, Feb. 16-18, 2004. pp. 135-140. (ISBN: 0-88986-375-X)



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